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Neutron capture cross section and capture gamma-ray spectra of ^{138}Ba in the keV-neutron energy region

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Abstract. The neutron capture cross sections and the capture γ-ray spectra of ^{138}Ba were measured in the astrophysically important energy region. Measurements were made at neutron energies from 15 to 80 keV. The neutron energy was determined by the time-of-flight method. The γ-ray spectra showed that the primary transition pattern strongly depended on the incident neutron energy. The neutron capture cross sections were derived by the pulse height weighting technique. The present cross section values were compared with evaluated cross section data and previous measurements.

1 Introduction

Barium isotopes are important to understand the s-process nucleosynthesis[1]. The neutron capture cross sections of these isotopes are necessary to predict the production yields in the nucleosynthesis model. ^{138}Ba has the smallest neutron capture cross section among the stable Ba isotopes because of the closed neutron shell structure. The ^{138}Ba(n,γ)^{139}Ba cross section has a large uncertainty. The neutron capture reaction of ^{138}Ba is dominated by resolved neutron resonances in the astrophysically relevant energy region. The resonance parameters of ^{138}Ba have been measured by several groups[2–5]. The Maxwellian averaged neutron capture cross section has been experimentally determined by the activation method using a pseudo-Maxwellian neutron spectrum source at $kT = 5$ and 23 keV[6, 7].

In the present work, we measured the neutron capture cross section of ^{138}Ba in the energy region from 15 keV to 80 keV by the time-of-flight (TOF) method. Our experimental setup has a very short flight length, thus leading to a lower time resolution of TOF than the previous TOF experiments for ^{138}Ba(n,γ)^{139}Ba. Each neutron resonance cannot be resolved with the present time resolution. The obtained cross sections are averaged values in coarse energy bins. However the detection limit is smaller than the previous measurements. The high sensitivity to small cross section allows for measuring small non-resonant component such as direct capture process which cannot be measured by resonance analysis method. In addition, capture γ-rays were detected with a NaI(Tl) detector, giving not only TOF counts but also capture γ-ray spectra, which cannot be measured with a C_6D_6 detector used in the previous resonance analysis measurements. The capture γ-ray spectra contain important information on primary transitions from the capture state.

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2 Experiments and Data Analysis

Experiments were performed at the Research Laboratory for Nuclear Reactors at the Tokyo Institute of Technology. Incident neutrons were generated through the ^{7}Li(p,n)^{7}Be reaction by a pulsed proton beam from a Pelletron accelerator bombarding a lithium target. The flight length from the neutron source to the sample was 12 cm. Capture γ-rays from the sample were detected with an anti-Compton NaI(Tl) spectrometer. The details of the experimental method and the data analysis procedure can be found elsewhere[8]. An isotopically enriched ^{138}Ba sample (enrichment: 99.80%) in chemical form of $BaCO_3$ was used. The net weight of ^{138}Ba was 29.84 g. After removing absorbed moisture by heating at 150°C for 6.5 h, the sample powder was encased in a graphite container. The sample size was 56.2 mm in diameter and 12.7 mm in thickness. A gold sample (55 mm diam. and 32.3 g) was used as standard for cross section measurements.

The TOF and pulse height of each detected event were recorded sequentially in list-format data files. Six TOF gates (15-19 keV, 19-23 keV, 23-33 keV, 33-40 keV, 40-65 keV, 65-80 keV) for analysis were chosen from resonance structure observed in the TOF spectrum. Pulse height spectra were obtained by sorting the data with the six TOF gates. After background subtraction, the neutron capture yields were derived from the net pulse height spectra by the pulse-height weighting technique[9]. The absolute cross sections were determined from the ratio of ^{138}Ba to ^{197}Au yields and the JENDL-4.0 evaluated ^{197}Au(n,γ)^{198}Au cross section. Corrections for neutron

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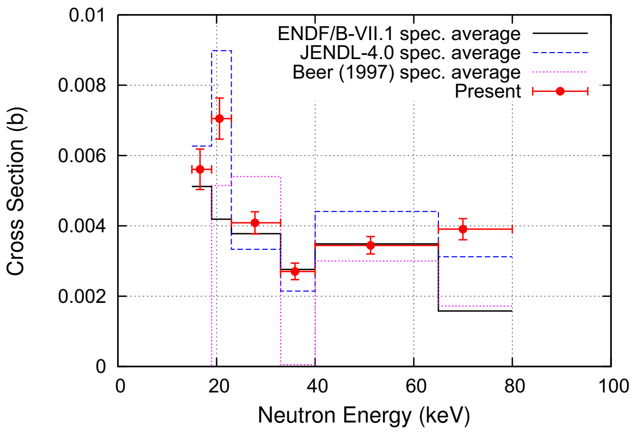

Figure 1. Neutron capture cross section of ^{138}Ba.

self shielding, multiple scattering and impurities in the sample were made.

3 Results

It is found that the γ-ray spectra drastically changed with the incident neutron energy. The ratio between the primary transition intensities to the ground and first excited states of ^{139}Ba changed. The spin and the parity of the ground and first excited states are $7/2^-$ and $3/2^-$, respectively. Strong transition to the ground state ($7/2^-$) was observed. The spin and parity of most of the reported resonances were unknown. Some resonances were assigned to *s* or *p* wave resonances[10]. If the transition to the $7/2^-$ ground state occurs at *p* wave resonances, $E2$ transition is required. On the other hand, if the transition is dominant $E1$, *d* wave resonances must exist. For further quantitative discussion, theoretical estimation is necessary.

Figure 1 shows a preliminary result of the ^{138}Ba(n,γ)^{139}Ba cross section. The indicated errors include statistical errors and systematic uncertainties mainly for the gold standard cross section, neutron transport corrections, impurity correction and corrections for undetected γ-rays under the discrimination energy. The horizontal bars indicate the energy bins. Cross sections of ENDF/B-VII.1, JENDL-4.0 and calculated from resonance areas in Ref. [5] are also shown for comparison. The cross sections were averaged with the incident neutron spectrum of the present experiments. ENDF/B-VII.1 and the present cross section are in good agreement except for the energy regions of 19-23 and 65-80 keV. However ENDF/B-VII.1 does not adopt all reported resonances. Instead, background cross sections were introduced to reproduce activation measurements of Ref. [6, 7]. In JENDL-4.0, most of the adopted resonances were based on Ref. [3]. Most recent resonance data of Ref. [5] have not been adopted yet. Calculations from the Beer's resonance areas do not agree with the present results.

4 Summary

We measured the neutron capture cross sections and the capture γ-ray spectra of ^{138}Ba in the neutron energy region from 15 to 80 keV. The incident neutron energy was determined by the TOF method. Capture γ-rays were detected with an NaI(Tl) detector with Compton suppression shield. The pulse height spectra showed that the primary transition pattern strongly depended on the incident neutron energy. The strong ground state transition suggests the possible existence of *d* wave resonances but quantitative discussion is required. The neutron capture cross sections were derived by the pulse height weighting technique. The present cross section values were compared with ENDF/B-VII.1, JENDL-4.0 and previous measurements by Beer et al. ENDF/B-VII.1 shows a good agreement with the present results. However the ENDF/B-VII.1 evaluation of ^{138}Ba is very compromise way, in which background cross sections were introduced to reproduce activation measurements, instead of using resonance parameters. On the other hand, even most recent resonance data by Beer *et al.* does not match with the present results. Comprehensive evaluation including the present data is necessary to give reliable cross section values of the ^{138}Ba(n,γ)^{139}Ba reaction.

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